Clamshell or sternotomy for double lung or heart-lung transplantation? 1

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Abstract

Objective: To evaluate the influence of either incision on the lungs and chest wall. Methods: Ninety-two double lung (DLT) or heart-lung (HLT) transplantations were done since January 1990. There were 22 (24%) hospital deaths, leaving 70 patients with complete data for evaluation. We did 38 DLT and 32 HLT for end-stage chronic respiratory failure \( n = 22 \) and primary \( n = 34 \) or secondary \( n = 14 \) pulmonary hypertension, using 37 fourth or fifth interspace clamshell incisions and 33 median sternotomies. Results: The clamshell group included a higher percentage of DLTs (73 vs. 33%, \( P = 0.001 \)) but recipient age, gender, preoperative diagnosis, bronchial anastomotic complications, number of cytomegalovirus infection, episode of acute rejection per patient-months and incidence of bronchiolitis obliterans were not statistically different between the two groups. At a follow-up time of 3.7–2 years, the overall 5-year survival of 57% was not influenced by the type of incision. The clamshell incision caused sternal overriding in 12 (32%) patients, and eight surgical clamshell revision were necessary as compared with one median sternotomy (\( P = 0.02 \)). The clamshell incision was associated with a significantly higher incidence of postoperative chronic pain (27 vs. 6%, \( P = 0.02 \)). Postoperative mechanical properties of the chest wall were significantly (\( P < 0.0001 \)) worse in the clamshell-group patients while the intrinsic properties of the airways were not different. Conclusions: The clamshell incision results in more postoperative deformity, chronic pain, and impaired function as compared with median sternotomy. A bilateral anterolateral thoracotomy without division of the sternum is proposed for the sequential bilateral lung transplantation technique.

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1. Introduction

In the early days of cardiac surgery, the heart and both aspects of the pericardium were approached through a transverse sternothoracotomy (or clamshell incision) (Fig. 1). Although better tolerated in pediatric cardiac surgery [1], the clamshell incision is associated with significant postoperative pain and prolonged respiratory insufficiency in adults. Unsurprisingly, it was rapidly abandoned as median sternotomy came into the avant-garde. More recently, however, the clamshell incision has regained surgical interest due to its superb exposure of both pleural cavities and mediastinum in lung transplantation [2,3], bilateral pulmonary and mediastinal tumors [4], complex cardiac defects [1] and mediastinal infections [5].

Double lung transplantation is now world-wide performed through the clamshell incision with the lungs replaced sequentially, as well as heart-lung transplantation when diffuse and dense apical and or posterior pleural adhesions may be anticipated. However, as experience increased, it has been our impression that the early and late postoperative courses of clamshell recipients were more stormy than that of sternotomy patients. We therefore reviewed all transplant recipients since 1990, and the generated results are presented here.
2. Patients and methods

2.1. Recipient population

This study includes 92 patients with end-stage vascular or parenchymal disease who underwent consecutive double lung (DLT) or heart-lung (HLT) transplantation from January 1990 to March 1998. There were 22 (24%) hospital deaths, leaving 70 patients with complete data for evaluation. We did 38 DLT and 32 HLT for end-stage chronic respiratory failure (n = 22) and pulmonary hypertension (n = 48), using 37 clamshell incisions and 33 median sternotomies. Although remarkable changes in the management of transplant recipients occurred over the years, there were no significant differences between patients having a clamshell or sternotomy incision regarding age, gender, type of pretransplantation disease and waiting-list time (Table 1). These management changes included the introduction of surveillance transbronchial biopsy, prophylactic antibiotics tailored to the results of microbiologic cultures obtained from the airways of the donor and recipient at harvesting, cytomegalovirus (CMV)-negative blood and blood products for seronegative donors and recipients, serum antigens measurements in all CMV-patients other than D-/R-, ganciclovir therapy for the treatment and prevention of CMV D-/R-infection.

2.2. Recipients selection

Candidates for DLT or HLT were less than 55 years old and had limited functional capacity, defined as New York Heart Association (NYHA) functional class III or IV, caused by end-stage parenchymal or vascular disease. All recipients underwent spirometry, arterial blood gases, exercise oxygen titration, quantitative perfusion and ventilation scans, and right heart catheterization with measurement of pulmonary arterial and pulmonary capillary wedge pressures, and cardiac index. Coronary arteriography was performed in patients of 40 years or more. Right and left ventricular ejection fraction were estimated by radionuclide ventricular ejection fraction. Candidates with a NYHA class IV pulmonary hypertension and a cardiac index of 2.1 L/min per m², right atrial pressure of more than 10 mmHg, and pulmonary vascular resistance more than 20 Wood units, despite failure or contraindication to prostacycline infusion were listed for HLT, as were those with a left ventricular ejection fraction of less than 35%, significant coronary artery disease, or complex congenital heart diseases. All patients with Eisenmenger’s syndrome had surgically uncorrectable complex congenital heart disease and were listed for HLT. All other candidates were listed for DLT.

2.3. Operative technique

Pulmonary and heart preservation solutions were Papworth solution (using leukocyte-depleted blood), and conventional crystalloid cardioplegia. The clamshell incision was performed 31 times through the fourth, and six times through the fifth intercostal spaces, and principally in patients who were extensive pleural adhesions were anticipated (e.g. chronic pulmonary embolism) and patients requiring sequential bilateral lung transplantation (SBLT). All HLTs were made using the same technique [6]. The technique for the 38 double lung transplantations evolved over the years from en bloc proximal bi-bronchial (n = 18) to the en bloc tracheal with bronchial artery revascularization (n = 5), to what has become the gold standard, the SBLT (n = 15) (Table 2). As shown, the clamshell group included a higher percentage of DLTs (73 vs. 33%, P = 0.001). Parenchymal volume reduction was made in three sequential bilateral recipients (one sternotomy recipient and two clamshell-recipients) at the end of the implantation because of the size-mismatch. All implantation procedures required institution of cardiopulmonary bypass.

2.4. Immunosuppression

Azathioprine (2.5 mg/kg) and methylprednisolone (1 gm) were given intravenously immediately before graft perfusion. The induction immunosuppression regimen consisted of anti-lymphocyte globulin (0.1 mg/10 kg per day 1–5), intravenous cyclosporin to maintain target whole blood levels between 250 and 350 mg/ml and azathioprine (2.5 mg/kg per day). Corticosteroids were started at the 5th postoperative day (1 mg/kg per day). Maintenance immunosuppression was achieved by triple therapy, the dose adjustments of cyclosporin (6–10 mg/kg per day) were made according to the whole blood levels of cyclosporin-A (200–300 ng/ml) [7].

2.5. Postoperative surveillance

CMV infections were defined by the isolation of the...
CMV in a culture obtained from any body site in the absence of symptoms of CMV infection, histological evidence of CMV disease or rejection. Ganciclovir was given at 5 mg/kg every 12 h when antigenemia became positive until its disappearance. All patients received Acyclovir at the dose of 800 mg three times a day from postoperative days 7–90. Transbronchial biopsies and bronchoalveolar lavages were systematically made at day 30 and 90 postoperatively, and each time abnormal signs and symptoms suggestive of rejection or infection occurred. Acute rejection was defined histologically and treated with intravenous methylprednisolone (0.5 gm/day) for 3 days for the first two episodes followed by an increment of oral corticotherapy. Refractory rejection episodes were treated either with a new methylprednisolone cycle or with mono- or polyclonal antilymphocytic immuglobulins. Obliterative bronchiolitis (OB) was defined as a permanent obstructive lung disease, resistant to increased immunosuppression, and by the presence of dense scar tissue in the lamina propria of the terminal and respiratory bronchioles airway wall with a mononuclear cell infiltrate.

2.6. Functional measurements

The mobiles volumes were evaluated with the vital capacity (VC) and forced expiratory volume in 1 s (FEV₁). The intrinsic properties of the small airways were assessed using the forced expiratory flow rate between 25 and 75% of vital capacity (FEF₂₅–₇₅). All were expressed as percentage of predicted. Consenting patients underwent symptom-limited exercise testing. Post-exercise blood pressure and EKG were continuously monitored. Maximal oxygen consumption (VO₂max) was recorded as a percentage of predicted normal values. Maximal work rate was expressed as absolute values (Watts) and as percentage of predicted values.

2.7. Statistical analysis

Data are expressed as mean ± SD of n number of observations. Quantitative and qualitative comparisons of pre- and post-operative characteristics between clamshell and median sternotomy recipients were made by one-way analysis of variance with Fisher’s protected least significance difference, the Mann–Whitney rank sum test, Wilcoxon signed rank test, and χ² analysis. Survival was calculated from the date of surgery until death or the date of last follow-up (censored). Survival was estimated by the product-limit method [8], and differences on their distribution were evaluated via the log rank test [9], for univariate analysis, and Cox’s proportional hazards stepwise model [10], for multivariate analysis. Data were analyzed using a software package (STATVIEW 4.02, Abacus Concepts, Berkeley, CA). The a priori level of significance was at P < 0.05.

3. Results

3.1. Surgical complications

The difference between the two groups are listed on Table 3. Sternal overriding occurred in 12 or 32% of clamshell patients and in none of the sternotomy-patients (P = 0.02). Eight clamshell patients (22%) required surgical re-exploration vs. one (3%) revision for median sternotomy (P = 0.03). The clamshell incision was associated with a significantly higher incidence of postoperative chronic pain (27 vs. 6%, P = 0.02). There were 11 anastomotic complications (16%), equally distributed among the two study-groups; all but two occurred in patients harvested with the en bloc double lung technique (P = 0.0008).

Table 3
Post-operative surgical complications

<table>
<thead>
<tr>
<th></th>
<th>Clamshell (n = 37)</th>
<th>Sternotomy (n = 33)</th>
<th>Overall (n = 70)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sternal over-riding (yes vs. no)</td>
<td>12 vs. 25</td>
<td>0 vs. 33</td>
<td>12 vs. 58</td>
</tr>
<tr>
<td>Postoperative incisional pain</td>
<td>10 vs. 27</td>
<td>2 vs. 31</td>
<td>12 vs. 58</td>
</tr>
<tr>
<td>Phrenic nerve palsy</td>
<td>2 vs. 35</td>
<td>1 vs. 32</td>
<td>3 vs. 57</td>
</tr>
<tr>
<td>Anastomotic complications (yes vs. no)</td>
<td>6 vs. 31</td>
<td>5 vs. 28</td>
<td>11 vs. 59</td>
</tr>
</tbody>
</table>

\( \chi^2 \) test: *P = 0.0016, **P = 0.04.
3.2. Medical complications

The number of CMV infection, number of acute rejection and episodes of acute rejection per patient-months, incidence of bronchiolitis obliterans were not statistically different between the clamshell and sternotomy patients (Table 4). By contrast, the episodes of CMV infection were significantly ($P < 0.0001$) lower in clamshell recipients.

3.3. Survival

With a follow-up time of 3.7 – 2 years, the overall 2- and 5-year survivals were 71 and 57%, respectively, and the median survival 63 months. Twenty-eight patients (40%) died from OB ($n = 16$), pulmonary infection ($n = 4$), malignancies ($n = 4$), acute pancreatitis ($n = 2$), and other causes ($n = 2$). Patients with end-stage vascular disease, those receiving a DLT and those operated on through a clamshell incision, had a non-significant worse survival than their counterparts but the only significant ($P = 0.01$) and independent predictor of survival was the absence of OB.

3.4. Functional outcome

Postoperative mechanical properties of the chest wall, as assessed by the VC and FEV$_1$ were significantly ($P < 0.0001$) worse in the clamshell-group patients (Fig. 2). By contrast, the intrinsic mechanical properties of the lung, as assessed by the FEF$_{25-75}$ were not different between the two incision-groups (Fig. 3). Twenty patients consented to perform exercise tolerance measurements, without showing significant differences in the VO$_{2\text{max}}$ ($60 \pm 11$ vs. $58 \pm 15$) or maximal work load ($54 \pm 11$ vs. $55 \pm 13$) between the clamshell and sternotomy groups, respectively.

4. Discussion

The clamshell thoracotomy consists of a bilateral submammary skin incision followed by a transverse division of the pectoralis major muscles, to allow access to the fourth or fifth intercostal spaces anteriorly, ligation and division of the internal mammary arteries and veins, incision of the parietal pleura bilaterally, and division of the sternum either transversely or using an inverted v-shaped incision. Division of the serratus muscles at the lateral incision and the intercostal muscles posteriorly allow further release of the intercostal spaces and gain of additional exposure.

Its major advantages are its superb exposure of both...
pleural cavities and lung hila, easy control of bleeding and division of pleural adhesions, and rapid access to the heart for institution of cardiopulmonary bypass. Disadvantages to this approach include the longer time both to make and to close the incision, more pain than median sternotomy, and overriding or disruptions at the transverse sternotomy site. Although the sternotransverse site is usually closed with two to three standard sternal wires placed across the sternum, sternal overriding or disruption can be observed in as much as 60% of patients. New surgical devices [11] or the use of K wires [12] have lowered these complications, but the incidence of early and late postoperative sternal pain and sternal overriding and deformity still remains high, and represents a frustrating issue in otherwise healthy transplant patients. Moreover, since in most recipients the usual amount of soft tissue is almost lacking, patients having a clamshell incision are more likely to develop sternal or wound infection. The presented results demonstrate that the clamshell incision is associated with a significantly higher incidence of early and late surgical complications and impairment of the chest wall function than median sternotomy in adult DLT or HLT recipients. Surgical re-exploration and sternal overriding were respectively registered in 22 and 32% of the clamshell-patients, and this rate compares favorably with other series [1,11]. Although the clamshell incision appears to generated less intercostal neuralgia than the posterolateral thoracotomy [12], it was associated in our experience with a significantly higher incidence of durable postoperative chronic pain as compared with median sternotomy, being the pain located mainly at the sternotomy site.

More distressingly, the movement of the chest wall and its compliance were significantly more restricted in clamshell-patients than in sternotomy-patients, as demonstrated by the VC and FEF25-75 data. A more than plausible explanation of this figure is that changes in the anteroposterior and transverse dimensions of the chest wall are primarily affected by the intercostal muscles and accessory muscles of the respiration, and are dependent on the mobility of the rib cage. Thus incisions that results in deformation of the rib cage (sternal overriding or disruption) and weakness or paralysis of the accessory respiratory muscles (intercostal, major pectoralis, and serratus muscles) may restrict chest wall expansion and compliance. These affections are indeed more peculiar to the clamshell incision rather than the median sternotomy, in which the degree of sternal fixation is higher and the amount of surgically divided accessory muscles of the respiration is lower, explaining the higher chest wall compliance of sternotomy patients. That these results depend on the incisional trauma caused by the clamshell...
incision per se rather than the quality of the transplanted grafts is further confirmed by the absence of significant differences between the intrinsic mechanical properties of the large and small airways (FEF_{25–75}) of the two groups. The absence of difference in VO_{2max} or maximal work rate between the two groups of incisions-patients may be related to the persistent peripheral muscle dysfunction and/or absence of substantial differences in the exercise capacity, which is common in lung transplant recipients and is remarkably similar regardless of the underlying disease and type of transplant procedure [13,14].

The practical implication of our report is that the clamshell incision should be avoided in DLT-recipients. A valid alternative is to perform the sequential bilateral technique through two anterolateral thoracotomies without division of the sternum (Fig. 4). It does not require (i) the sacrifice of both internal thoracic arteries so that they may be eventually used for bronchial artery revascularization or further coronary grafting; (ii) sternal division, avoiding thus the risks of sternal overriding, disruption and infection, and (iii) it lessens phrenic nerve and/or brachial plexus overstretching [5]. While it conserves the superb exposure of the clamshell incision, the heart can be easily accessed for institution of cardiopulmonary bypass by opening the pericardium on the right side and cannulating the ascending aorta and right atrium. These arguments were practically confirmed by us in our last 10 transplant procedures made without having any surgical incisional-complications, and by others [15].

In conclusion, median sternotomy remains the gold standard for the HLT. Since the clamshell incision is associated with a significantly higher incidence of early and late surgical complications and impairment of the chest wall function, a bilateral anterolateral thoracotomy without section of the sternum is proposed for the sequential bilateral lung transplantation.

References


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Fig. 4. Schematic view of a double anterolateral thoracotomy without section of the sternum (and internal mammary pedicles) for performing the sequential bilateral lung transplantation.
Appendix A. Conference discussion

**Dr A. Haverich** (Hannover, Germany): This, to my knowledge, is the first presentation that depicts the long-term functional data for the various incisions. I could ask now for the long-term function if you do bilateral thoracotomy without division of the sternum, but since you only started in January of this year, these data are probably not available. What would be your estimate?

**Dr Macchiarini**: What we first saw, is in fact that we shrank to zero, almost zero, the surgical morbidity like the postoperative pain and sternal overriding, and infection at the sternotomy level. I am quite sure that with anterolateral thoracotomies without division of the sternum, the long-term function outcome will be better. I think that Walter Klepetko this morning, presented very preliminary, but self-speaking, data concerning the functional outcome between clamshell incision and two lateral thoracotomies.

**Dr W. Klepetko** (Vienna, Austria): I think your conclusion that the clamshell incision is not peanuts for the patient is completely right and we follow that. This morning, we presented the series on 21 patients operated via two small anterior thoracotomies. The interesting thing is, when we compared it with a historical group of clamshell incisions, that the restrictive pattern of lung function was much less in the anterior thoracotomy as compared with the clamshell. We don’t have data on the long-term follow-up of these patients, and this is an interesting question, of course.

The clamshell incision intends to offer you a better view in the thoracic cavity and to give you a better possibility to manage with significant adhesions and surgical problems. So I really wonder why the rate of rethoracotomies in your group of clamshell incisions was higher as compared with the sternotomy group? Can you give some explanation on that, and comment on the reasons for rethoracotomy in those patients?

**Dr Macchiarini**: Maybe I was too quick, but these were re-thoracotomies because of previous pleurectomy or so on, and we decided to operate on the patients through a clamshell incision.

**Dr Klepetko**: Have you compared the rethoracotomy rate in those two groups? Have you compared the rate of rethoracotomies for bleeding reasons?

**Dr Macchiarini**: In the sternotomy versus clamshell?

**Dr Klepetko**: Yes.

**Dr Macchiarini**: Eight versus one.